Forest Health Protection

Pacific Southwest Region
Northeastern California Shared Service Area

Date: September 5, 2019
File Code: 3420

To: District Ranger, Feather River Ranger District, Plumas National Forest

Subject: Evaluation of stand conditions with respect to forest insects and disease within the French Creek project, Plumas National Forest (FHP Report NE19-04)

At the request of Brandon Stephens, District Silviculturist, Feather River Ranger District, Danny Cluck, Forest Health Protection (FHP) Entomologist, visited the French Creek project area (French Creek 1 and 2) with district staff on June 13, 2019. The objective was to evaluate the current forest health conditions within the project area, discuss what influence these conditions would have on stand management objectives and provide recommendations as appropriate. Brandon Stephens, Clay Davis, District NEPA Planner, and Will Brendecke, Acting Forest Silviculturist, accompanied me to the field.

Key findings:

- High stand density is putting some stands at risk to increased levels of bark beetle-caused tree mortality during periods of drought. Many of these stands are also at risk to high severity wildfire.
- Ponderosa pine plantations and some pockets of pure ponderosa pine within mixed conifer areas are overstocked and at risk to increased levels of tree mortality caused by western pine beetle. Some of these stands experience elevated levels of mortality during the last drought.
- Mixed conifer stands within and adjacent to the French Creek project area also experienced elevated levels of sugar pine mortality caused by mountain pine beetle during the last drought.
- High fuels loads, consisting of an abundance of dead-down trees and live and dead brush have put some stands at risk to increased fire behavior.
- Several stands burned at low severity within the 2018 Camp Fire which could result in elevated levels of fire-injured tree mortality over the next few years.
- Thinning and prescribed fire are highly recommended throughout the project area to reduce tree density and surface and ladder fuel levels. Specific recommendations are provided in this evaluation.

Danny Cluck
Forest Entomologist
530-252-6431
dcluck@fs.fed.us

Bill Woodruff
Plant Pathologist
530-252-6880
wwoodruff@fs.fed.us

Description of the project area

The French Creek project area is located ~10 miles north of Berry Creek, CA at elevations ranging between 2,300 and 4,500 feet (39.802368N and 121.371860W). Annual precipitation ranges between 55 and 70 inches. Most of the area is comprised of Sierra mixed conifer consisting of white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), red fir (*Abies magnifica*), California black oak (*Quercus kelloggii*), bigleaf maple (*Acer macrophyllum*), tan oak (*Notholithocarpus densiflorus*) and Pacific madrone (*Arbutus menziesii*). Most of the lower elevation stands and south facing slopes are pine dominated mixed conifer while higher elevation stands and north facing slopes are mostly fir dominated mixed conifer. Shade-tolerant pine species are mostly restricted to the overstory with limited regeneration due to overcrowding by white fir and in some cases, Douglas-fir. Red fir is mixed with white fir at the highest elevations of the project area.

The 2019 Camp Fire burned through a majority of the proposed project acres but mostly at low severity. Moderate and high severity acres were removed from the French Creek project and are currently being salvage logged with the Big Bar project.

Project objectives

The French Creek project proposes to reduce hazardous fuels and stand density through commercial and precommercial thinning, mastication of brush and prescribed burning. Ponderosa pine plantations will be thinned to low densities emphasizing stand and species variability. Mixed conifer stands will also be thinned but retain relatively higher stocking, especially in California spotted owl habitat, but emphasize density reduction in overstocked groups of ponderosa pine, California black oak release, a reduction in shade tolerant tree species, and removing smaller diameter trees from the understory. The residual stands will be more open, increasing the amount of available soil moisture and sunlight for individual trees and reducing the risk to high severity wildfire. Hazard trees will be identified and removed along all roadways. The project will be accomplished in two phases, French Creek 1 in FY20 and French Creek 2 in FY21 or FY22. French Creek 1 encompasses the southwestern and lower elevation portion of the project and French Creek 2 covers the northeastern and higher elevation areas.

Forest insect and disease conditions

Tree mortality caused by forest insect and disease pest agents is occurring at very low levels across the project area (Figure 1). This follows the current pattern for the entire NE California region where a return to normal to above normal precipitation since 2017 has greatly improved tree health and vigor.

Agents/hosts observed during this site visit:

- Low levels of scattered white fir mortality caused by fir engraver beetle (*Scolytus ventralis*) and most likely associated with Heterobasidion root disease (caused by *Heterobasidion occidentale*).
- A few scattered ponderosa pine killed by western pine beetle (*Dendroctonus brevicomis*).
- Mountain pine beetle (*Dendroctonus ponderosae*)-caused mortality of a few sugar pine.

- White pine blister rust (*Cronartium ribicola*) infections were suspected to have caused older top-kill in large diameter sugar pine on Big Bar Mountain.

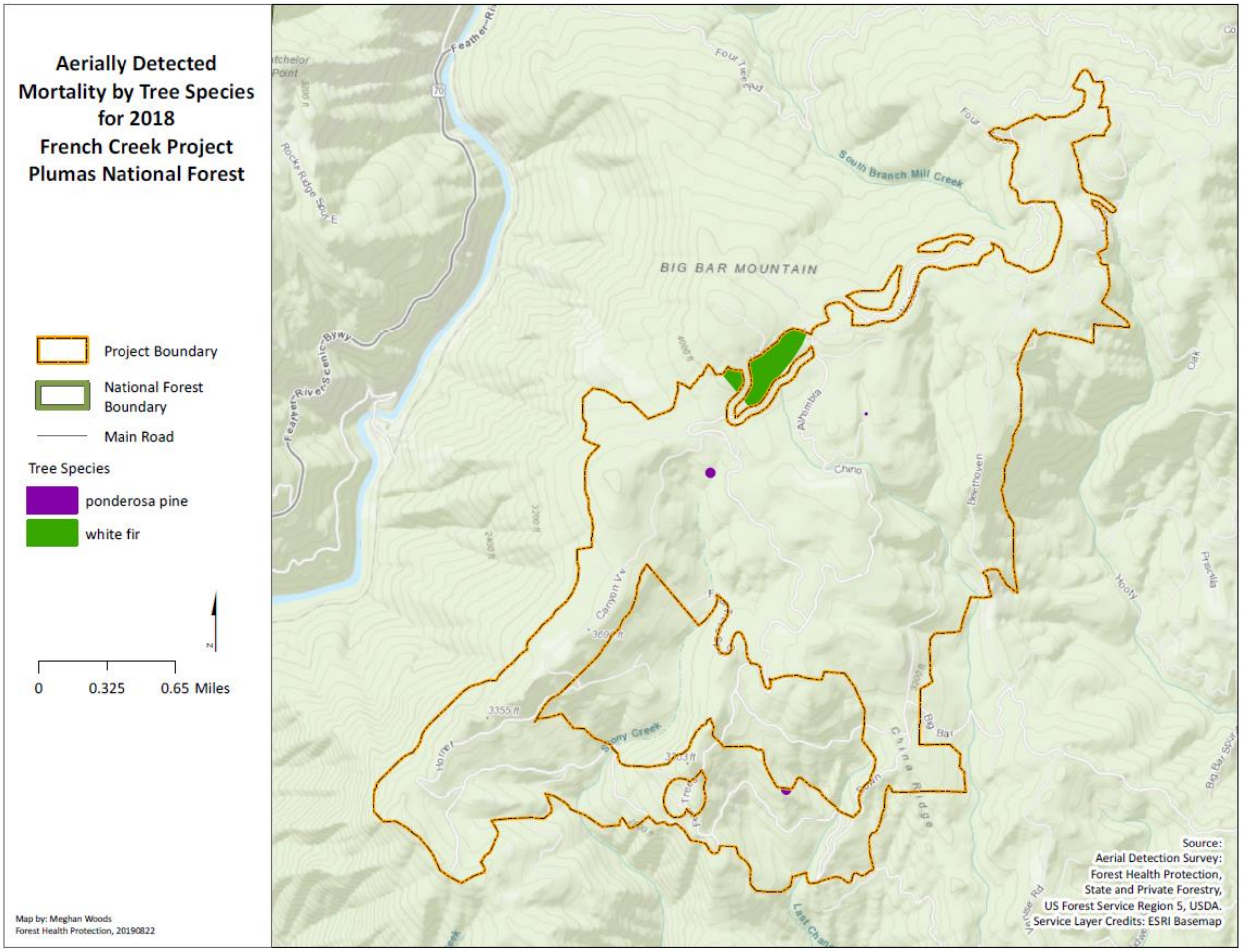


Figure 1. Areas of tree mortality by species mapped by Aerial Detection Surveys (ADS) in 2018.

Stand conditions and tree mortality related to recent and future climate trends

Most of the forested areas in the French Creek project area are in an overstocked condition and some experienced an elevated level of tree mortality caused by bark beetles during the recent drought from 2014 to 2016. Forest Health Protection Aerial Detection Surveys mapped and photographed several tree mortality locations within and adjacent to the project area in 2016 (Figures 2 - 5 and Table 1)). Elevated levels of bark beetle-caused tree mortality in the project area, as well as in the rest of the Sierra Nevada range, are strongly associated with periods of below normal precipitation and high stand density.

Forest Health Protection recently developed a treatment priority map for Region 5 to help land managers prioritize thinning treatments at the landscape level. This map depicts forested areas on National Forest System lands that are the most susceptible to drought and bark beetle-caused tree mortality based on forest type, average tree diameter and stand density. These areas also meet the criteria of existing on slopes <=35% and being outside of wilderness areas, wild and scenic river corridors and designated roadless areas. Additional criteria include not having burned at moderate to high severity since 1998 and not having been thinned since 2005. In addition to being overly dense, these areas have a history of tree mortality during drought resulting in heavy fuel loads and higher risk of stand replacing wildfire. Highest priority areas consist of high-

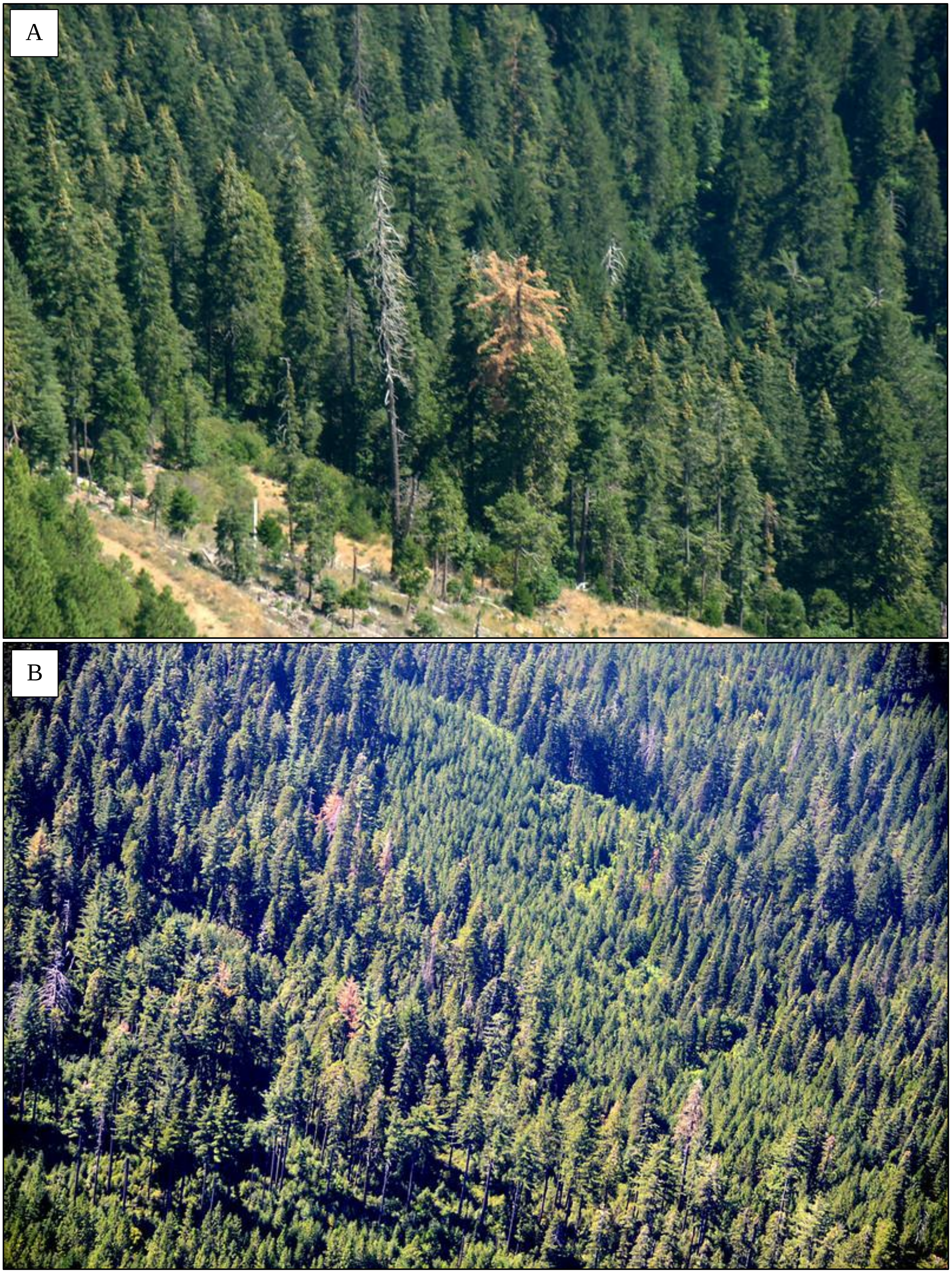


Figure 2. Single sugar pine (A) and scattered sugar pine (B) mortality within and adjacent to French Creek project area in 2016. (FHP Aerial Detection Survey 2016)

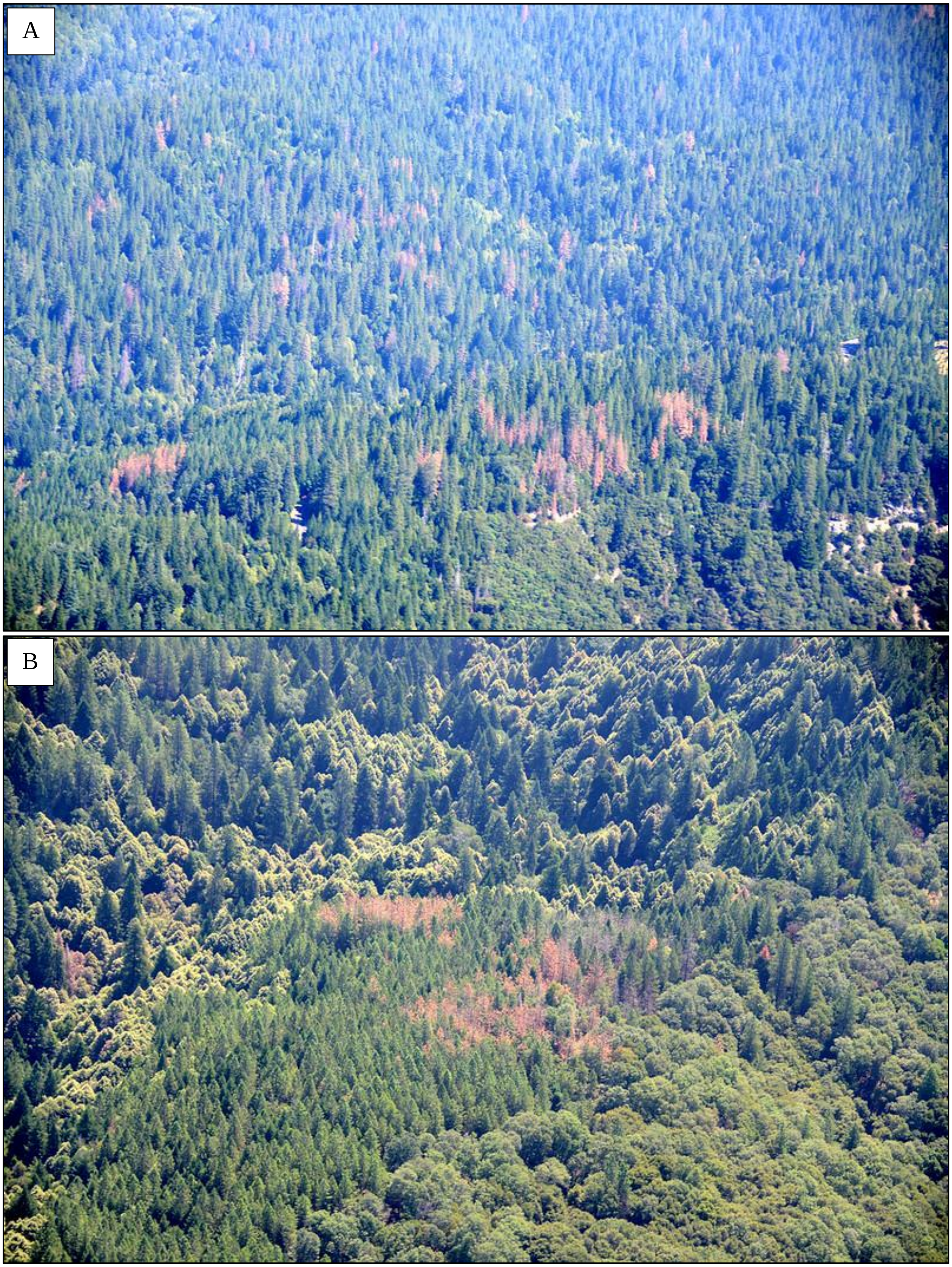


Figure 3. Group killing of ponderosa pine by western pine beetle in native stands (A) and plantations (B) within and adjacent to the French Creek project area. (FHP Aerial Detection Survey 2016).

Table 1. Acres with tree mortality, estimated dead trees per acre, estimated total # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (CA Division 2) by water year (Oct-Sept) within the French Creek project area.

Year	Acres	Dead Trees/Acre	Total # of Dead Trees	PHDI[1]
2018	34	115	3.4	-1.87
2017	188	194	1.0	2.49
2016	186	1,757	9.5	-1.78
2015	91	239	2.6	-3.03
2014	183	344	1.9	-3.12
2013	3	8	2.9	-1.62
2012	49	50	1.0	0.37
2011	161	162	1.0	2.59
2010	68	156	2.3	0.19
2009	131	366	2.8	-2.69

[1] Palmer drought values show a relationship to tree mortality. PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.

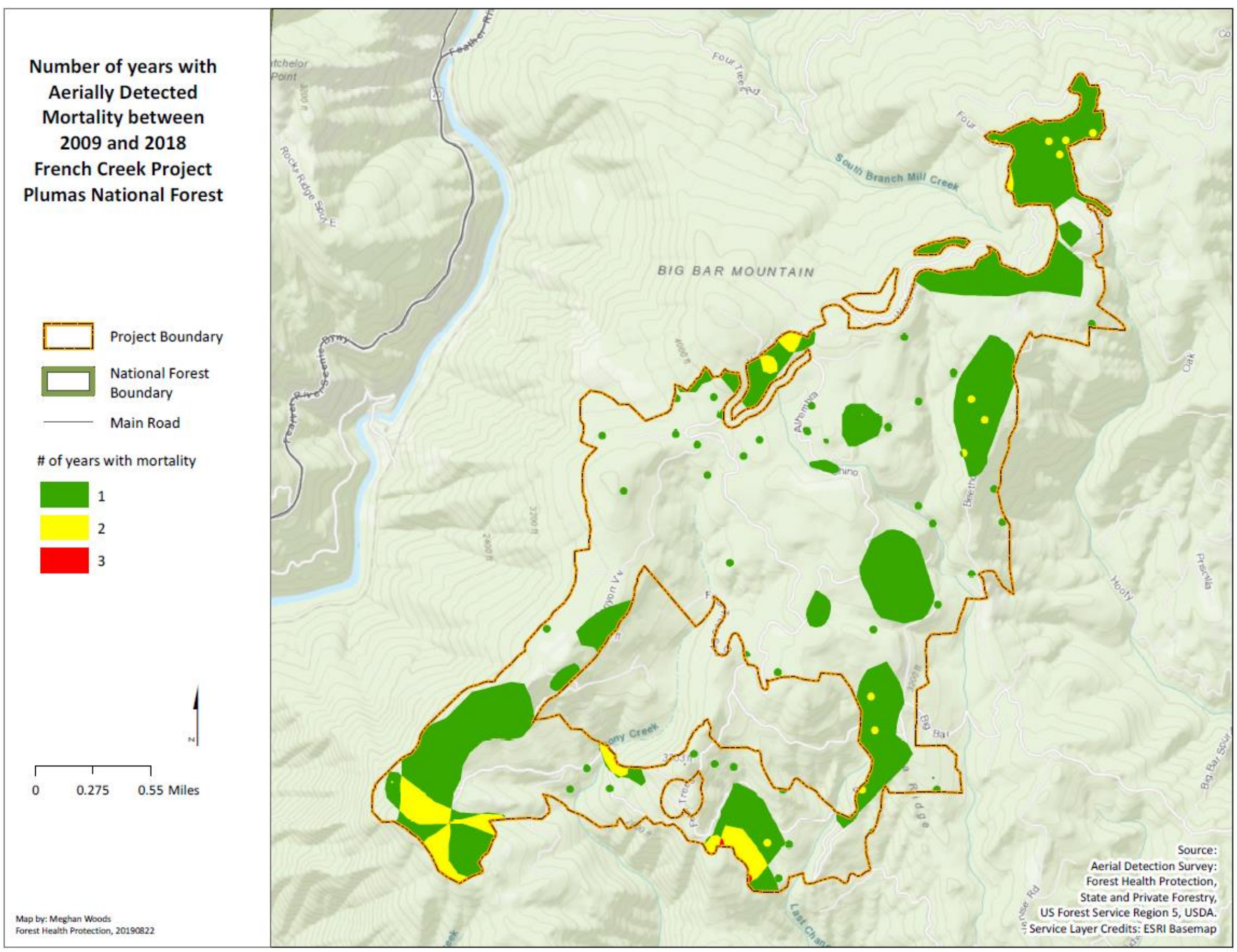


Figure 4. Number of years with mapped mortality by Aerial Detection Surveys (ADS) between 2009 and 2018.

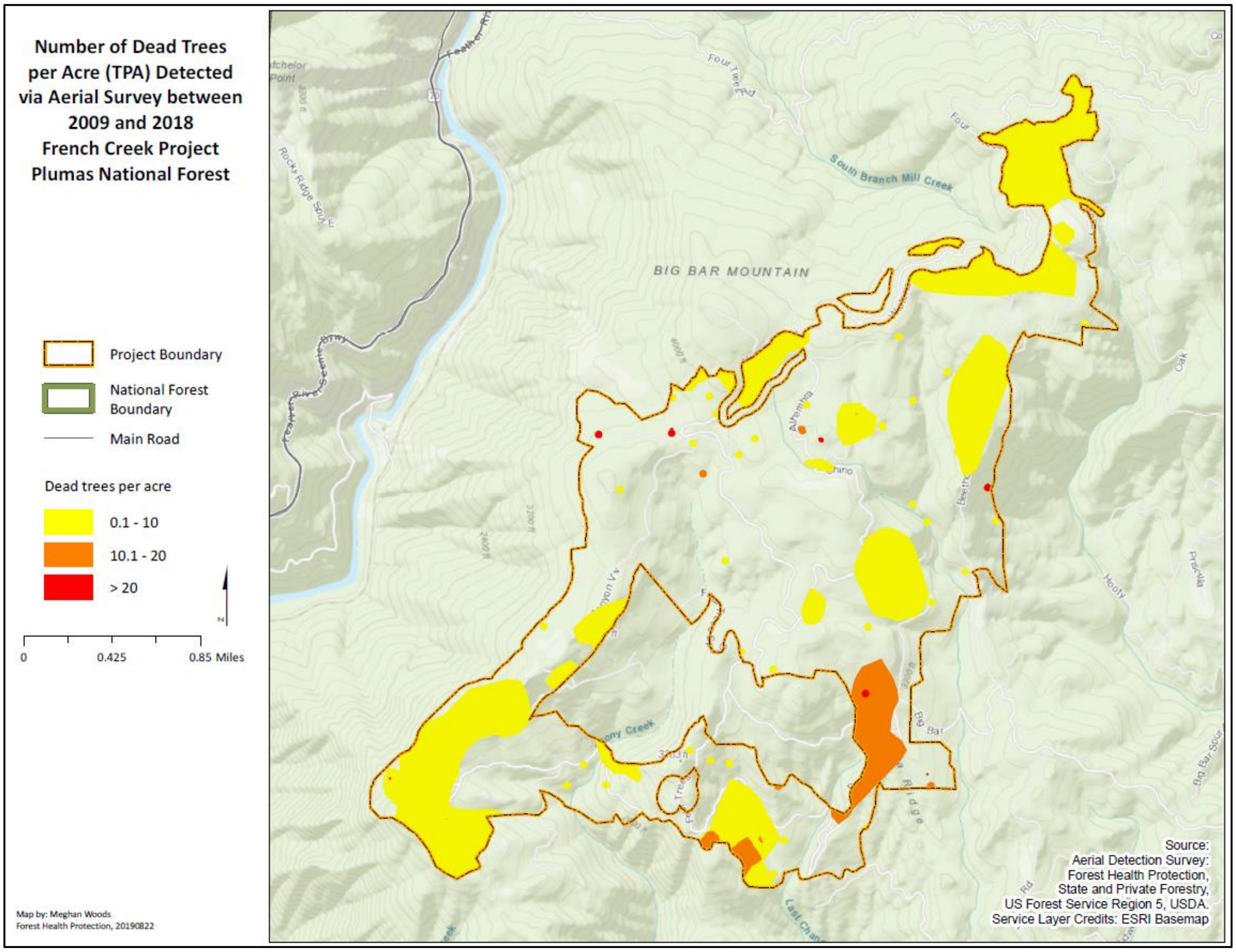


Figure 5. Cumulative dead trees per acre mapped by Aerial Detection Surveys (ADS) between 2009 and 2018.

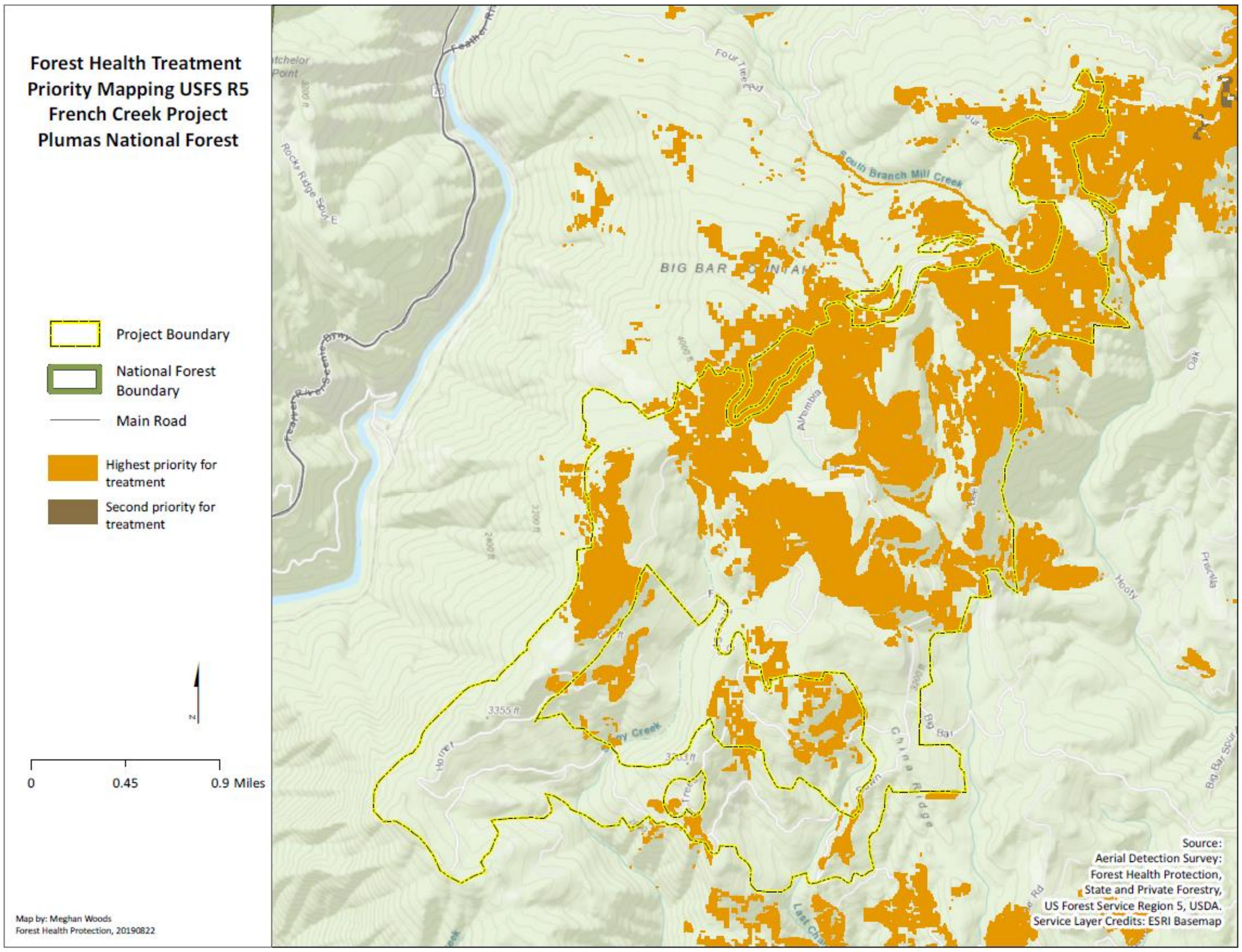
density pine stands, pine-dominated mixed conifer stands, and fir-dominated mixed conifer and white fir stands growing on historically pine dominated sites. Second priority areas consist of high-density fir-dominated mixed conifer and white fir stands on wetter sites. All mapped stands are California Wildlife Habitat Relationship size class 4, 5 and 6.

Figure 6 shows treatment priority areas within the French Creek project boundary. This mapping effort utilized remotely sensed data to create treatment priority layers for large scale planning and may not be accurate at the stand level. The forest should still use stand records and stand exam data to identify treatment areas and develop silvicultural prescriptions.

The most recent National Insect and Disease Risk Map (2012) also shows many stands within and adjacent to the French Creek project that are currently at risk to high levels of bark beetle-caused tree mortality (Figure 7). This risk is based on precipitation, stand density and average tree diameter. This version of the map does not incorporate the risk of mortality from diseases such as Heterobasidion root disease and dwarf mistletoes which would increase the number of acres depicted.

Predicted climate change is likely to impact trees growing in this area over the next 100 years. Although no Plumas National Forest specific climate change models are available at this time, there is a consensus among California models that summers will be drier than they are currently.

Figure 6. Treatment Priority Areas* at risk to bark beetle-caused mortality within and adjacent to the French Creek project area



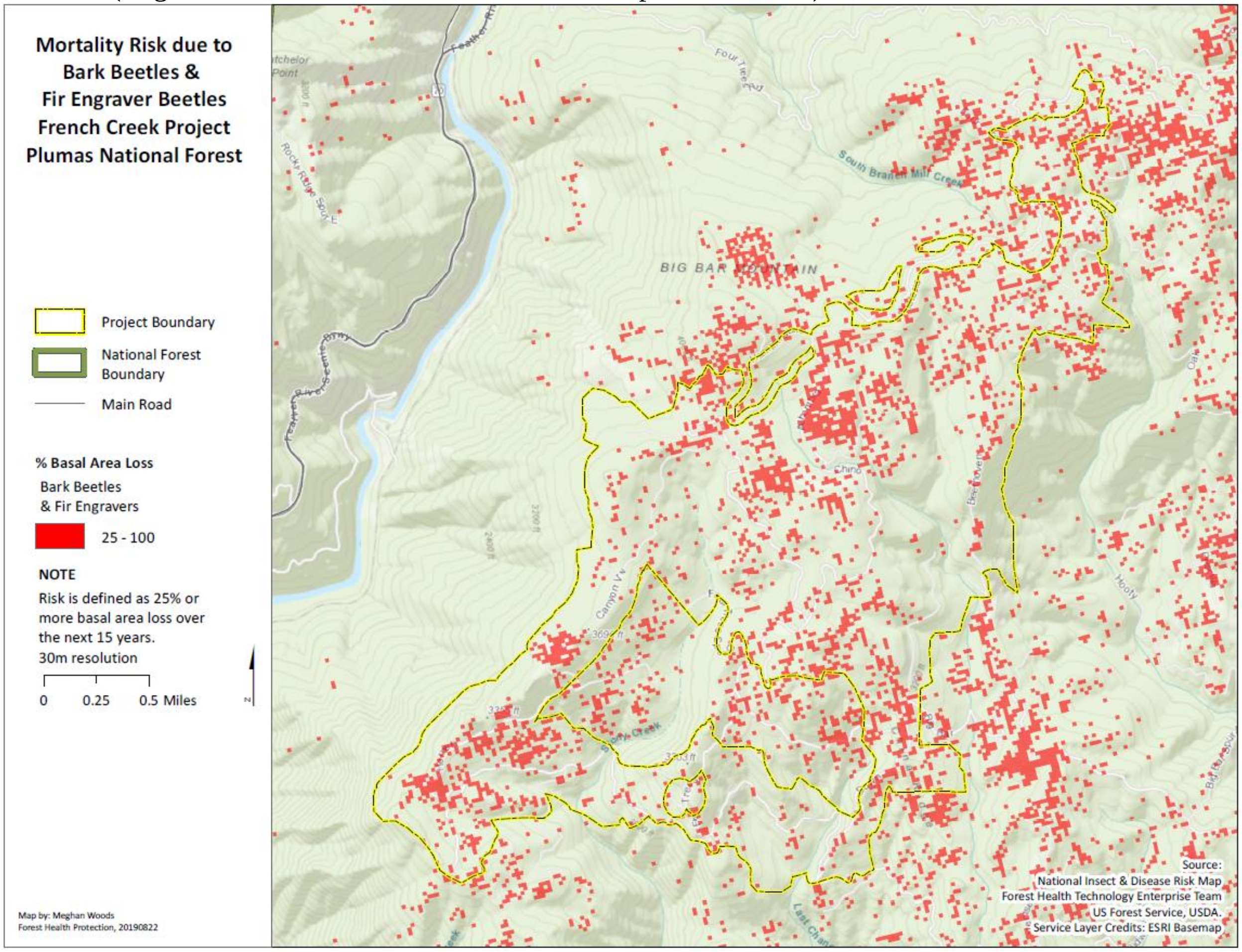
*Highest priority treatment areas include overly dense stands (>60% of maximum stand density index) of pine and pine-dominated mixed conifer stands as well as fir-dominated mixed conifer and white fir stands growing on historically pine-dominated sites. Second priority treatment areas include overly dense stands of fir-dominated mixed conifer and white fir. Mapped areas only include CWHR size class 4, 5 and 6 stands. Wilderness areas, inventoried roadless areas, wild and scenic areas, moderate to high severity burned areas since 1998, areas thinned since 2005, areas with >35% slope and all non-National Forest System lands were excluded from this analysis.

This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (K. Merriam and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Sierra Cascade Province, including the Plumas, Modoc, and Lassen National Forests*). The risk of bark beetle-caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant and root diseased white fir and overstocked stands of larger (>8” DBH) ponderosa pine growing on lower elevation, warmer sites. Improving the resilience of the French Creek project area to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

Discussion and recommendations

Ponderosa pine mortality caused by western pine beetle is probably the primary threat to forest health in the French Creek project second only to wildfire. Ponderosa pine growing in high

Figure 7. Risk of bark beetle-caused tree mortality based on precipitation, stand density and average diameter (Region 5 Forest Insect and Disease Risk Map 2012 version).



density stands in this area are at a much higher risk to large scale mortality than the other conifers due to the tree's susceptibility to an aggressive bark beetle species, western pine beetle, that can build up large populations over a short time period in response to drought. Therefore, ponderosa pine should be given special consideration when planning thinning treatments to reduce its susceptibility to successful western pine beetle attacks. In native mixed conifer stands, susceptibility could be decreased by reducing density to lower levels in ponderosa pine dominated pockets (<120 sq.ft./acre recommended) than what is appropriate for surrounding mixed conifer stands. Including the removal of suppressed individuals as well as any bark beetle infested trees will improve the efficacy of treatments. Sufficiently lowering the basal area in pine dominated pockets may reduce their canopy cover to below required thresholds. However, more basal area, and higher canopy cover, could be retained in adjacent mixed conifer areas to maintain a higher average throughout a stand.

High stand density combined with drought conditions cause extreme moisture stress in individual trees, thus reducing their ability to fend off bark beetle attacks. Healthy ponderosa pines defend themselves by producing resins that drown attacking beetles. When trees are stressed, resin pressure is reduced, and the probability of successful bark beetle attack is increased. High stand density may also improve conditions for the bark beetle pheromone communication system, which facilitates mass attacks on individual trees and groups of trees, by concentrating the pheromone plume under a full canopy.

The best strategy to decrease the amount of mortality in the long-term is to reduce stand density through thinning. Thinning will increase the health and vigor of residual ponderosa pines by reducing competition for limited soil moisture (Fettig et al. 2007). The District should consider reducing the SDI in ponderosa pine dominated stands to below 230. SDI 230 is the defined threshold for the zone of imminent bark beetle caused mortality. Within this zone, endemic populations kill a few trees, but net growth is still positive (Oliver 1995). Thinning stands below this level will reduce the risk of additional bark beetle-caused mortality by reducing tree competition for limited water and nutrients.

Dense ponderosa pine plantations would benefit by the same reductions in stand density with an emphasis placed on creating spatial heterogeneity and enhancing conditions for other tree species such as Douglas-fir, incense cedar and black oak. Thinning prescriptions should aim to reduce basal area to a range of 60 to 120 sq.ft./acre. This should effectively reduce the risk of significant western pine beetle-caused mortality.

Thinning treatments are recommended in mixed conifer to improve forest health conditions and increase resiliency to disturbance. Treatments should aim to reduce stand density to a level that significantly lowers the risk of bark beetle-caused mortality. In most cases, thinning to a relative density of 25 - 40% (relative to the maximum Stand Density Index, or SDI) for a specific conifer species or for a weighted composition of conifer species will effectively reduce competition for limited water and nutrients and reduce the susceptibility to future bark beetle-caused tree mortality for many years. The District should consider an SDI max of 450 for drier mixed conifer (Long and Shaw 2005) on south facing slopes and ridge tops and SDI max 550 (Long and Shaw 2012) for mixed conifer on more mesic aspects and down in drainages.

Thinning mixed conifer stands to lower densities will likely result in more rapid tree growth, creating a canopy of taller and larger diameter trees in a shorter timeframe. Density reduction needs to focus on the removal of shade tolerant species, with an emphasis on lower and mid canopy trees but some removal of upper canopy white fir may be needed to provide growing space for more desirable and drought resilient species. North et al 2017 suggests that "management strategies designed to preserve and facilitate the growth of tall trees while reducing the cover and density of understory trees may improve forest resilience to drought and wildfire while also maintaining or promoting the characteristics of owl habitat." They also state that the "reduction of sub-canopy and intermediate-size trees may reduce water competition increasing large tree resilience to beetle attack while opening up more growing space to accelerate tree growth." Removing competing trees from the base of large diameter pines combined with stand level thinning resulted in a measured increase in annual increment growth in old growth ponderosa and Jeffrey pine on the Lassen National Forest (Hood et al 2017).

The presence of Heterobasidion root disease in white fir should be considered when developing silvicultural prescriptions. Root diseased true fir are at a higher risk for fir engraver attacks than uninfected trees during droughts. Leaving high numbers of root diseased trees in the overstory will likely lead to higher levels of mortality over the long-term, reducing canopy cover and increasing fuels. Leaving these trees will also reduce opportunities for successful regeneration of shade intolerant species that are not susceptible hosts to *H. occidentale*.

The best option for managing *H. occidentale* in white fir is to reduce its overall abundance in the stand and remove severely infected trees (based on declining crown characteristics). Various sized openings can be created in the stand to facilitate planting of non-hosts such as ponderosa and sugar pine. Placing these openings on known or suspected root disease pockets will enhance the effectiveness of this strategy for reducing overall infection levels. In addition, greatly reducing white fir stocking in stands that have a non-host overstory component will allow for natural non-host regeneration and create a more resilient species composition over time.

It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14" in diameter to reduce the chance of creating new infection centers of *Heterobasidion irregulare* and *H. occidentale* formerly referred to as P-type and S-type annosus root disease, through harvest activity.

When planning thinning treatments, it should be recognized that the target stand density is an average to be applied across the landscape and some variability may be desired. Individual high value trees, such as large mature pines and black oaks, should benefit by having the stocking around them reduced to lower levels. Areas of pure or nearly pure ponderosa pine would also benefit from lower stocking levels as well as an increase in species diversity. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees, or on more mesic north-facing slopes. Incorporating the concepts of GTR 220 and 237 will address many of these issues and be consistent with Regional ecosystem restoration goals.

Sugar pine should be retained as much as possible during any thinning operation in order to preserve genetic diversity, especially white pine blister rust (*Cronartium ribicola*) resistant individuals. An exception to this would be thinning suppressed trees within pure sugar pine groups to reduce inter-tree competition. White pine blister rust, a non-native pathogen, has continued to weaken and kill this species over most of its range since its introduction into the Pacific Northwest in 1910. Identification and protection of local rust resistant trees for seed collection, if not already occurring, will aid in the future planting of rust resistant seedlings. Planting selected openings created through thinning operations with rust resistant stock would help insure this species persists in the area.

The grove of large diameter white pine blister rust infected sugar pine with older top-kill observed on Big Bar Mountain appear to be relatively healthy. However, a few individuals are growing in suppressed crown positions, or have a low live crown ratio, and should be candidates for removal during the thinning operation. Thinning in this stand should attempt to create a more heterogeneous species composition by retaining other species as much as possible.

Accounting for delayed mortality of fire-injured trees

The Camp Fire burned very late in the year (November 2018) which resulted in cooler burning conditions than most wildland fires. The large areas of low severity burn within the French Creek project area appear to have caused minimal damage to crown and boles of trees. Random cambium sampling within charred portions of tree boles during this site visit at different elevations and on different tree species revealed low levels of cambium kill. The late timing of the fire was also after the flight period for most bark and woodboring beetle species and has likely resulted in lower post-fire insect activity than would otherwise be expected. Even with the apparent low levels of tree injury, the District should still anticipate some delayed mortality and should consider evaluating fire-injuries as part of the selection criteria when marking trees for retention or removal. Trees with obvious cambium damage and higher levels of crown kill should generally be selected for removal over trees with relatively less fire-injury.

Considerations for Rx fire

If prescribed fire is used as a follow-up treatment to stand thinning, it may result in unacceptable levels of tree mortality; depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to individual trees during the fire. Mature ponderosa pine, sugar pines and black oak are susceptible to lethal basal cambium damage during prescribed burns from the heat that develops in the deep duff and litter that accumulates at their bases. These duff mounds typically burn at a slow rate with lethal temperatures, causing severe injury to the cambium which girdles the trees. To protect individual high-value large diameter pine and black oak from lethal cambium damage, raking the duff away from the bases of these trees before burning (within 24" of the bole and down to mineral soil) is recommended.

Potential for funding thought the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding for thinning and removing green material from overstocked areas within the French Creek area. Thinning treatments that reduce stand density sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

Daniel R. Cluck
Forest Entomologist
NE CA Shared Services Area

cc: Brandon Stephens, District Silviculturist, Feather River RD
Clay Davis, District NEPA Planner, Feather River RD
Will Brendecke, Acting Forest Vegetation Officer, Plumas SO
Forest Health Protection, Regional Office

References:

Fettig, C.J.; Klepzig, K.D.; Billings, R.F.; Munson, A.S.; Nebeker, T.E.; Negrón, J.F.; Nowak, J.T. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle outbreaks in coniferous forests of the western and southern United States. Forest Ecology and Management. 238: 24–53.

Hood, S.M., Cluck, D.R., Jones, B.E., and Pinnell S. 2017. Radial and stand-level thinning treatments: 15-year growth response of legacy ponderosa and Jeffrey pine trees. *Restoration Ecology*. doi:10.1111/rec.12638

Long, J.N., and J.D. Shaw. 2005. A density management diagram for even-aged ponderosa pine stands. *West. J. Appl. For.* 20:205–215.

Long, J.N., and J.D. Shaw. 2012. A density management diagram for even-aged

Sierra Nevada mixed-conifer stands. *West. J. Appl. For.* 27(4):187-195.

North, Malcolm P.; Kane, Jonathan T.; Kane, Van R.; Asner, Gregory P.; Berigan, William; Churchill, Derek J.; Conway, Scott; Gutiérrez, R.J.; Jeronimo, Sean; Keane, John; Koltunov, Alexander; Mark, Tina; Moskal, Monika; Munton, Thomas; Peery, Zachary; Ramirez, Carlos; Sollmann, Rahel; White, Angela; Whitmore, Sheila 2017. Cover of tall trees best predicts California spotted owl habitat. Forest Ecology and Management. 405: 166-178.

Oliver, W.W., 1995. Is self-thinning in ponderosa pine ruled by Dendroctonus bark beetles? In: Proceedings of the 1995 National Silviculture, Workshop, GTR-RM-267. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, C.O., pp., 213–218.

Insect and Disease Information

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis,* has been intensivly studied and has proven to be an important factor in the ecology and management of ponderosa pine thoughout the range of the host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches DBH. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring through fall. Depending on the latidude and elevation, there can be from one to four generations per year.

Evidence of Attack

Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. Successful pitch tubes are red-brown masses of resin and boring dust. Relativly few, widely scattered white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheremones released during a successful attack attract other conspecifics. Attracted beetles may then spill over into nearby apparently healthy trees and overwhelm the tree with sheer numbers.

Life Stages and Development

These beetles pass thorugh the egg, larval, pupal and adult stages during a life cycle that varies in length dependent primarily on temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem then mine into the middle bark where they complete most of their development. Bluestain fungi inoculates the tree during successful attacks, blocking trachids and vessicles which contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions affecting Outbreaks

Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the Westsince 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles.Information from surveys conducted in the 1930's indicated enormous losses attributed to the western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size though successive beetle generation as is typical with Mountain Pine Beetle and Jeffreay Pine Beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing western pine beetle outbreaks. When healthy trees undergo a sudden and sever moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin to resist the attack. Any condition that results in excessive demand for moisture, such as inter-tree completion, competing vegetation, or protracted drought periods; or any condition that reduces the ability of the roots to supply water to the tree, such as mechanical damage, root disease or soil compaction, can cause moisture stress and increase susceptibility to attack by the western pine beetle. Woodpeckers, predacious beetles, and low temperatures act as natural control agents when beetle populations are low (endemic populations).

Fir Engraver

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater that 4” in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack

Fir engravers bore entrance holes along the main stem, usually in areas that are > 4” in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development

In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum,* into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year, however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks

Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Mountain pine beetle

The mountain pine beetle, *Dendroctonus ponderosae,* attacks the bole of ponderosa, lodgepole, sugar and western white pines larger than about 8 inches dbh. Extensive infestations have occurred in mature lodgepole pine forests. Group killing often occurs in mature forests and young overstocked stands of ponderosa, sugar and western white pines.

Evidence of Attack

The first sign of beetle-caused mortality is generally discolored foliage. The mountain pine beetle begins attacking most pine species on the lower 15 feet of the bole. Examination of infested trees usually reveals the presence of pitch tubes. Pitch tubes on successfully infested trees are pink to dark red masses of resin mixed with boring dust. Creamy, white pitch tubes indicate that the tree was able to "pitch out" the beetle and the attack was not successful. In addition to pitch tubes, successfully infested trees will have dry boring dust in the bark crevices and around the base of the tree. Attacking beetles carry the spores of blue-staining fungi which develop and spread throughout the sapwood interrupting the flow of water to the crown. The fungi also reduces the flow of pitch in the tree, thus aiding the beetles in overcoming the tree. The combined action of both beetles and fungi causes the needles to discolor and the tree to die.

Life Stages and Development

The beetle develops through four stages: egg, larva, pupa and adult. The life cycle of the mountain pine beetle varies considerably over its range. One generation per year is typical, with attacks occurring from late June through August. Two generations per year may develop in low elevation sugar pine. Females making their first attacks release aggregating pheromones. These pheromones attract males and other females until a mass attack overcomes the tree. The adults bore long, vertical, egg galleries and lay eggs in niches along the sides of the gallery. The larvae feed in mines perpendicular to the main gallery and construct small pupal cells at the end of these mines where they pupate and transform into adults.

Conditions Affecting Outbreaks

The food supply regulates populations of the beetle. In lodgepole pine, it appears that the beetles select larger trees with thick phloem, however the relationship between beetle populations and phloem thickness in other hosts has not been established. A copious pitch flow from the pines can prevent successful attack. The number of beetles, the characteristics of the tree, and the weather affect the tree's ability to produce enough resin to resist attack. Other factors affecting the abundance of the mountain pine beetle include nematodes, woodpeckers, and predaceous and parasitic insects. As stand susceptibility to the beetle increases because of age, overstocking, diseases or drought, the effectiveness of natural control decreases and pine mortality increases.

Heterobasidion Root Disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* (‘P’ type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* (‘S’ type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

White pine blister rust

White pine blister rust is caused by *Cronartium ribicola* an obligate parasite that attacks 5-needled pines and several species of *Ribes* spp. The fungus needs the two alternate hosts to survive, spending part of its life on 5-needled pines and the other on *Ribes* spp. The disease occurs throughout the range of sugar pine to the southern Sierra Nevada, but has not been reported further south. Infection of pines results in cankers on branches and main stems, branch mortality, top kill, and tree mortality.

Spores (aeciospores) produced by the fungus in the spring on pine bole or branch cankers are wind-disseminated to *Ribes* spp. where they infect the leaves. Spores (urediospores) produced in orange pustules on the underside of the leaves reinfect other *Ribes* spp. throughout the summer, resulting in an intensification of the rust. A telial spore stage forms on *Ribes* spp. leaves in the fall. Teliospores germinate in place to produce spores (sporida) which are wind-disseminated to pines and infect current year needles. Following infection, the fungus grows from the needle into the branch and forms a canker. After 2 or 3 years, spores are produced on the cankers and are spread to *Ribes* spp. to continue the cycle. Although blister rust may spread hundreds of miles from pines to *Ribes* spp., its spread from *Ribes* spp. back to pines is usually limited to a few hundred feet.

Branch cankers continue to enlarge as the fungus invades additional tissues and moves toward the bole. Branch cankers within 24 inches of the bole will eventually form bole cankers. Bole cankers result in girdling and death of the tree above the canker. Cankers that have margins more than 24 inches from the main bole are unlikely to reach the bole and only branch flagging will result.